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Binding energy of a Cooper pairs with non-zero center of mass momentum in d-wave superconductors

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Abstract

The binding energy of Cooper pairs has been calculated for the case of d-wave symmetry of the superconducting gap in layered cuprate superconductors. We assume that Cooper pairs are formed by the short range potential and then derive the binding energy in the form $\Delta_{\mathbf{kq}} = \Delta_x(\mathbf{q})\cos k_x a + \Delta_y(\mathbf{q})\cos k_y a + \Omega_x(\mathbf{q})\sin k_x a + \Omega_y(\mathbf{q})\sin k_y a$, where $\mathbf{q}$ is a total momentum of the pair. Numerical solutions of the self-consistent system of the integral equations for quantities $\Delta_x(\mathbf{q})$, $\Delta_y(\mathbf{q})$ and $\Omega_x(\mathbf{q})$, $\Omega_y(\mathbf{q})$ along different lines in q_x, q_y planes have been obtained. Anisotropy of the depairing total momentum (or depairing current) has been calculated.

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1. Introduction

The problem of the binding energy of a Cooper pair in the BCS model (phonon pairing mechanism) was discussed by Cooper in his pioneering paper [1] and later on by Casas et al. [2]. It was found that $\Delta_q = \Delta_0 - cq$, i.e. Cooper pairs are destroyed very fast when they start to move. This behavior of Cooper pairs is in strong contrast to usual bosons. The critical value of momentum at which Cooper pairs are self destroyed can be called as depairing momentum. In d-wave HTSC superconductors the energy gap is given by $\Delta_{\mathbf{kq}=0} = \Delta_0(\cos k_x a - \cos k_y a)/2$. As one can see the gap is zero along the diagonals in the Brillouin zone, i.e. when $k_x = \pm k_y$. Therefore, one can expect that depairing momentum (or depairing current) in d-wave superconductors should be also strongly anisotropic. To our knowledge this problem was not discussed, yet. The goal of present Letter is to cover this field. In Section 2 we shall derive the integral equation for the order parameter (or for simple explanation—the binding energy), using Hubbard projection technique. The results of numerical solution, derived equation, will be given in Section 3.

2. Model and integral equations

We start from the so-called singlet correlated band model for layered hole-doped cuprates [3]:

$$H = \sum_{ij\sigma} t_{ij}\psi_i^{pd,\sigma}\psi_j^{\sigma,pd} - \frac{1}{2}\sum_{i,j} J_{ij}\left(\psi_i^{\uparrow,\uparrow}\psi_j^{\downarrow,\downarrow} + \psi_i^{\downarrow,\downarrow}\psi_j^{\uparrow,\uparrow} - \psi_i^{\downarrow,\uparrow}\psi_j^{\uparrow,\downarrow} - \psi_i^{\uparrow,\downarrow}\psi_j^{\downarrow,\uparrow}\right)$$

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